

# Low Cost Hydrogen Production Platform

Cooperative Agreement: DE-FC36-01GO11004  
Project ID #: PD1

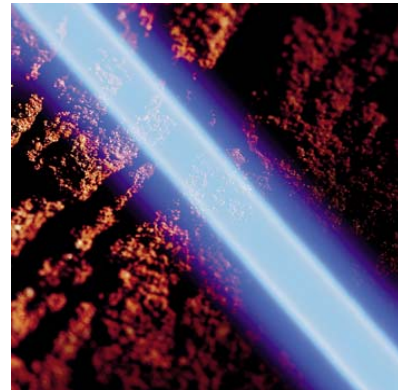
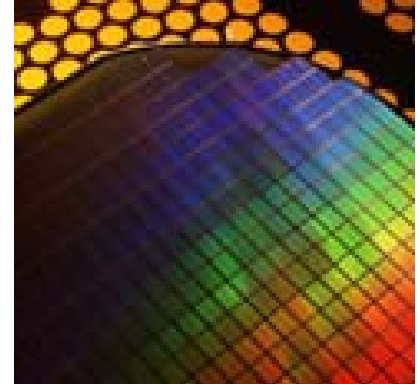
Timothy M. Aaron

## Team

Praxair - Tonawanda, NY  
Boothroyd-Dewhurst - Wakefield, RI  
Diversified Manufacturing - Lockport, NY

DOE Hydrogen Annual Review Meeting  
May 15 - 18, 2007

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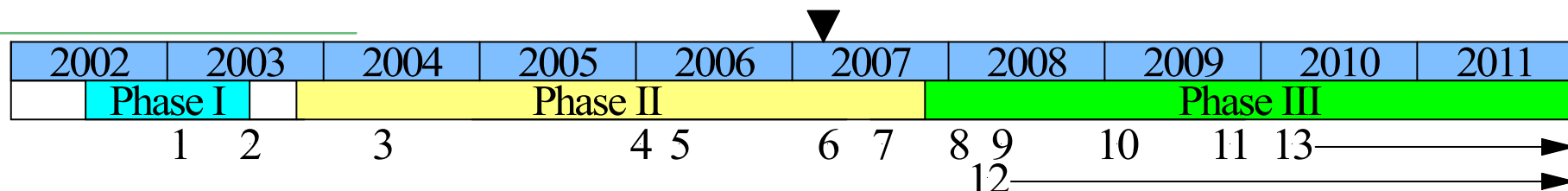


# ***LCHPP – Objectives***



- **Low cost on-site hydrogen production**
  - Existing technologies (SMR)
  - Transportation and industrial (4.8 kg/h)
  - Approach DOE goal of \$1.50 - \$2.00 kg (production only)
  - Gas station capacity and size - Single, easily installed skid
- **Fueling station integration**
  - Prototype construction
  - LAX fueling station
    - Installation and operation (2 years)
    - High pressure (700 bar) compression and dispensing
- **DOE barriers addressed (top 3) – Hydrogen Production**
  - A. Reformer capital costs
  - B. Reformer manufacturing
  - C. Operation and maintenance (O&M)
- **DOE barriers addressed (top 3) – Technology Validation**
  - C. Lack of hydrogen refueling infrastructure performance and availability data
  - D. Maintenance and training facilities
  - E. Codes and standards

# DOE Project Timeline



- **Phase I - Preliminary design**
  - 1. Preliminary component and system design
  - 2. Techno-economic study
- **Phase II - Detail design and optimization**
  - 3. Detail design and computer models
  - 4. Lab scale testing completed
  - 5. Full scale test apparatus constructed
  - 6. Proof of concept component testing completed
  - 7. Update system design and economic models
- **Phase III - Prototype system & fueling station integration**
  - 8. Complete prototype design
  - 9. Build prototype system
  - 10. Verify system performance and update economics
  - 11. Commercialize hydrogen system
  - 12. Hydrogen compression to 700 bar (10,000 psig) (LAX)
  - 13. Fueling station integration (LAX)

# Budget - LCHPP Program



- **Phase I**
  - Completed 06/03
- **Phase II (10/03 - 06/06) - In progress**
  - Total budgeted cost: \$1,989,933
  - Cost share: 50/50 – \$994,967 DOE/Praxair
  - FY2004 DOE funds (10/03 – 09/04) - \$120,000 (actual)
  - FY2005 DOE funds (10/04 – 09/05) - \$277,155 (actual)
  - FY2006 DOE funds (10/05 – 09/06) - \$300,000 (actual)
  - FY2007 DOE funds (10/06 – 09/07) - \$ 15,000 (to date)
  - DOE Phase II total DOE shortfall to date - **\$285,812**
- **Phase III (10/07 - 12/11) - Technology Validation**
  - Cost share: 50/50
  - FY2007 DOE funds (10/06 – 09/07) - \$0

# Approach

## ➤ Phase II – Hydrogen Production

- Complete component testing
- Prove system design
- Procure prototype long lead materials
- Update prototype design
- Final report and Phase III proposal

## ➤ Phase III – Prototype System

- HAZOP and safety reviews
- Construction
- Installation
- Control system
- Performance testing
- System economics
- Economies of scale
- Tooling cost analysis
- Market analysis

## ➤ Phase III – 700 bar compression (LAX)

- Analysis of options
  - Compression
  - Dispensing
  - Integration
- Project scope / definition
- HAZOP and safety reviews
- Site characterization & permitting
- Procurement
- Installation
- Operation and support

## ➤ Phase III – Prototype (LAX)

- Project scope / definition
- Site characterization & permitting
- Installation
- Operation and support

# Design Specifications

## ➤ Inputs

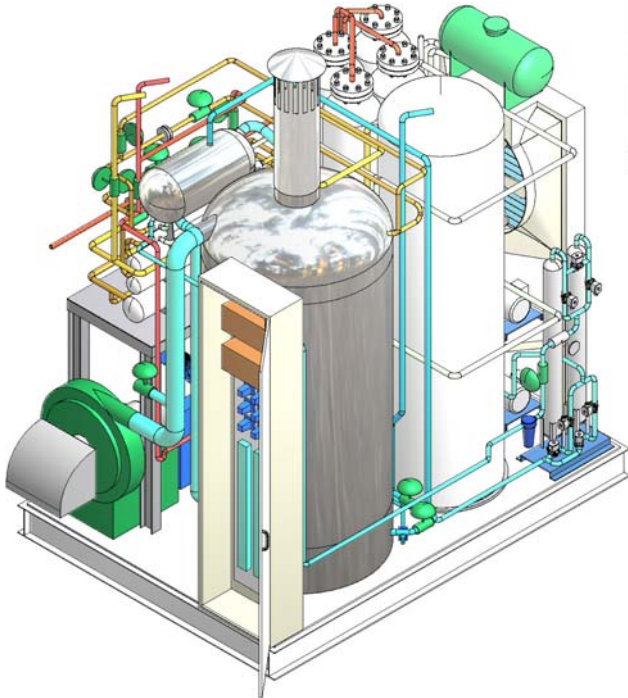
- Natural gas or equivalent
  - 5-30 PSIG
  - Std specifications
  - 850 SCFH
- Water
  - Std potable specs
  - <0.5 GPM
- Electrical
  - 220/480 VAC
  - 12 KW

## ➤ Outputs

- Hydrogen product
  - 4.8 kg/h (2,000 scfh)
  - <10 PPM CO
  - >99% purity
  - 100-120 PSIG
- Turndown capabilities
  - 50% minimum
- System package
  - 7'-6" x 10' x 10'
  - 18,000 lbs

# System

- Safety
- Compact, single skid
- Easily installed
- Welded construction
- Highly integrated



**PRAXAIR**





# High Temperature Component



## ➤ Functions

- Natural gas pre-heat
- Desulfurization
- Reforming
- Water-gas shift reactor
- Steam generation and superheat
- Combustion
- Air/exhaust/process heat exchange
- Syngas cooling

## ➤ Design

- DFMA
- Highly integrated
- Welded construction





# ***LCHPP – Accomplishments***

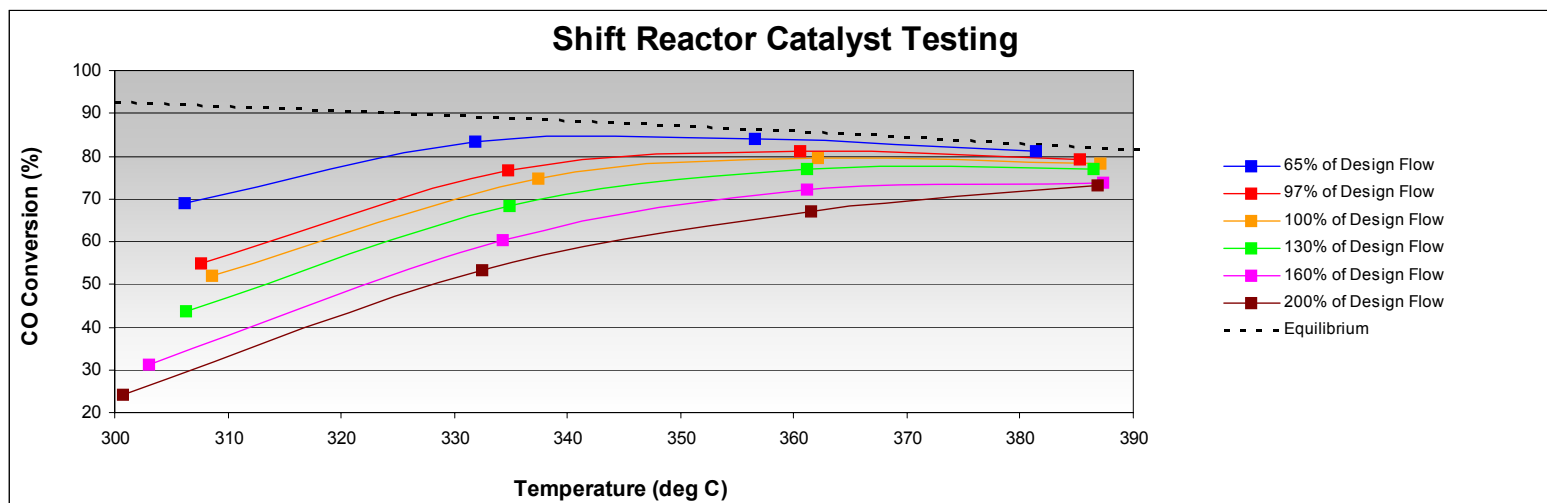
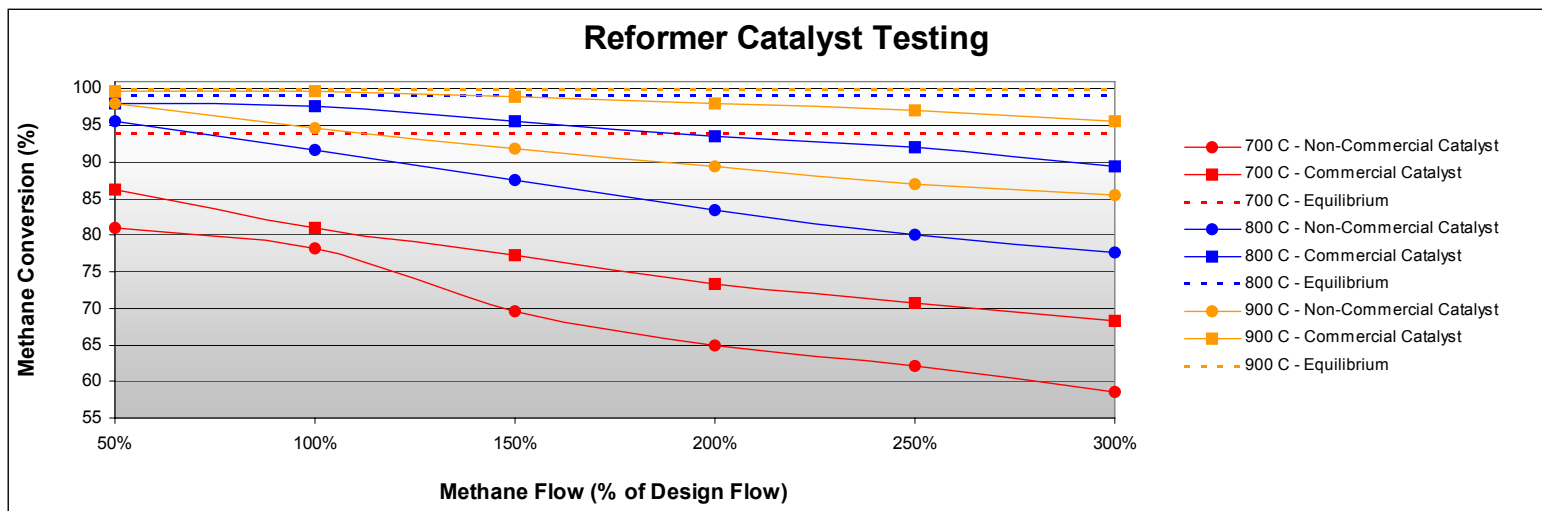


- **High temperature component**
  - Prototype design complete
  - Computer modeling complete
  - Material selection complete
  - Patent application submitted
- **Testing**
  - Lab scale reformer testing completed
  - Full scale testing continues
    - Reformer thermal management proven
      - ◆ Optimization testing underway
    - Catalyst
    - Burners
    - Steam system
    - Auxiliary components



Catalyst courtesy of Johnson-Matthey

# LCHPP – Accomplishments (Catalyst Testing)



# ***Accomplishments vs. DOE Barriers***

- **A. Fuel processor capital costs**
  - Highly integrated system
  - “Off-the-shelf” components used wherever possible
  - No significant system cost increases from last year
    - Higher material costs
    - Part count nearly identical
  - Unit capital cost comparable to plants 20x larger
  - Approaching overall DOE goals
  - Set new baseline for cost of H<sub>2</sub> from a small on-site system
- **B. Fuel processor manufacturing**
  - Extensive use of DFMA techniques (BDI)
    - Part count
    - Assembly time/complexity
    - Welded construction
  - Review of current design manufacturability (DMI)
  - Prototypes to verify results

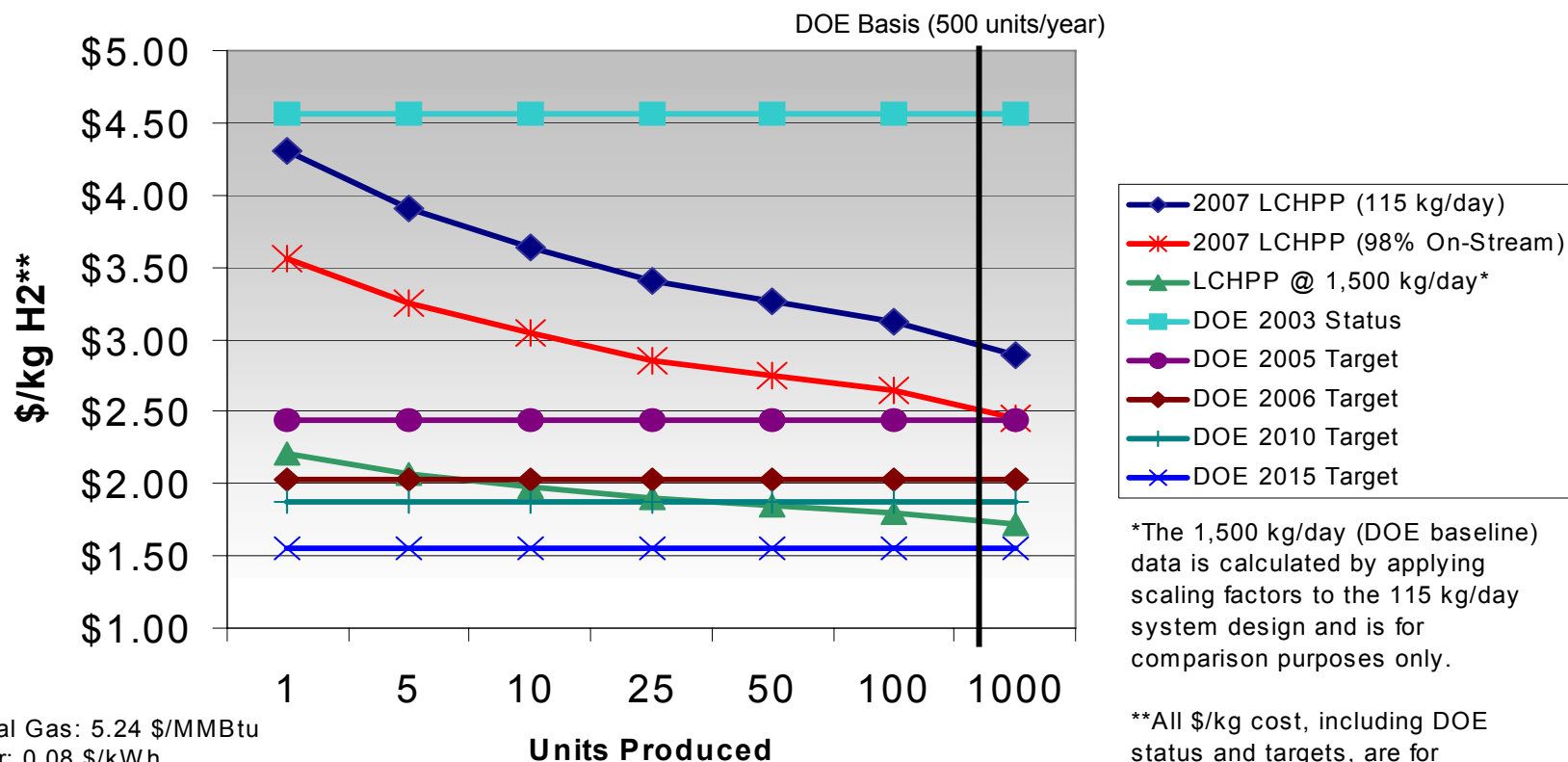
# ***Accomplishments vs. DOE Barriers - Continued***

- **C. Operation and maintenance (O&M)**
  - Control system remote capability
  - Easy access to critical equipment
  - High quality components used
  - Designed for 15 year life (7.5 year high temp component refurbishment)
- **D. Feedstock and water issues**
  - Currently natural gas reforming
  - Considerations given to alternative feedstocks
  - Water treatment and steam system being tested
- **F. Control and safety**
  - Risk analysis completed
  - Full HAZOP review of system will be performed
  - All applicable standards will be followed
  - Develop safety and design standards (ISO TC197 working groups)

# Technical Accomplishments / DOE Program Goals

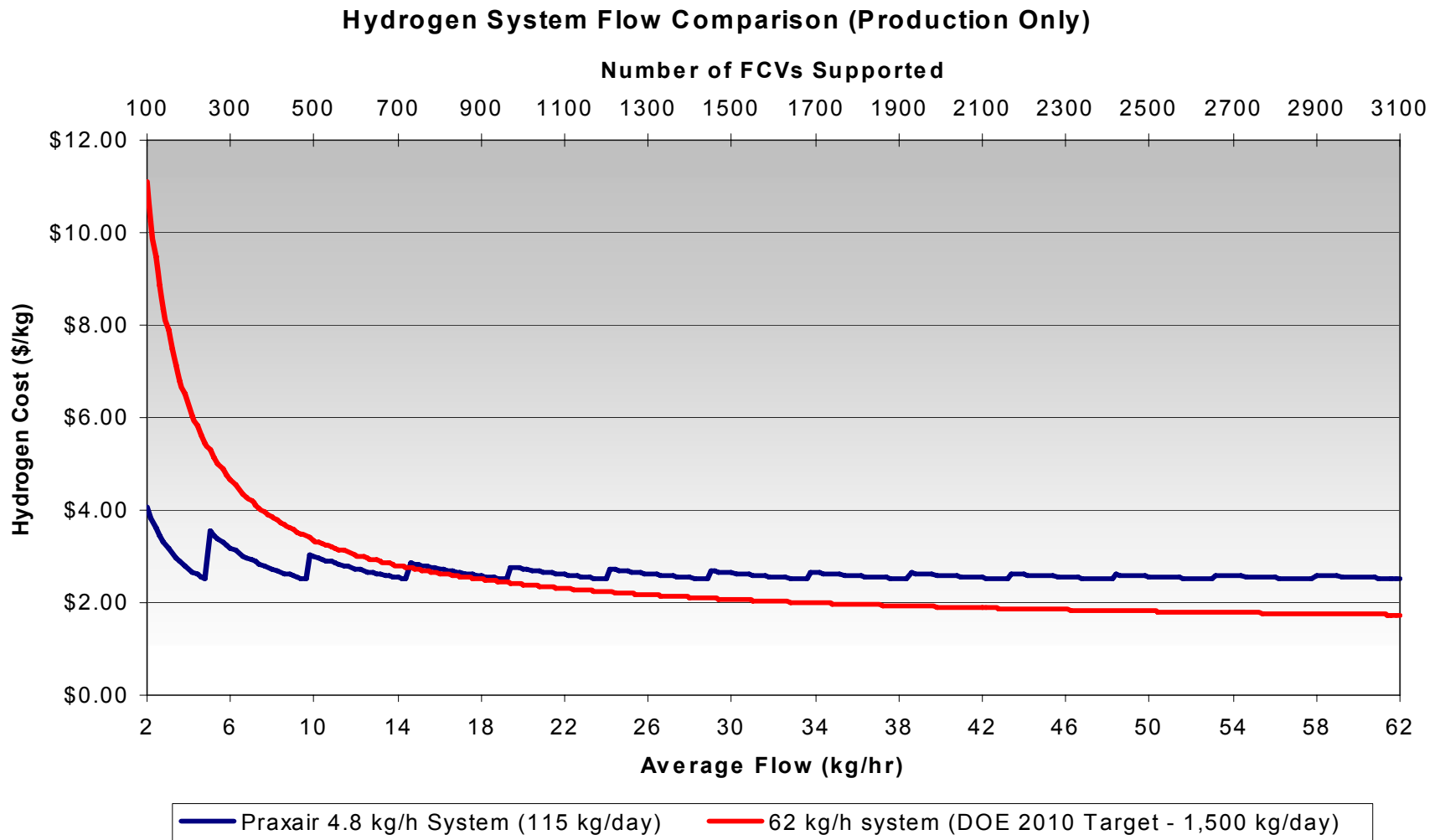


## H2 Cost vs Units Produced and H2 Flowrate



Natural Gas: 5.24 \$/MMBtu  
 Power: 0.08 \$/kWh  
 On-Stream Factor: 70%  
 Contract Life: 20 years  
 M&R (% of Cap per Year): 3%

# Fueling Station H2 Cost Analysis



# Hydrogen Cost vs. Gasoline



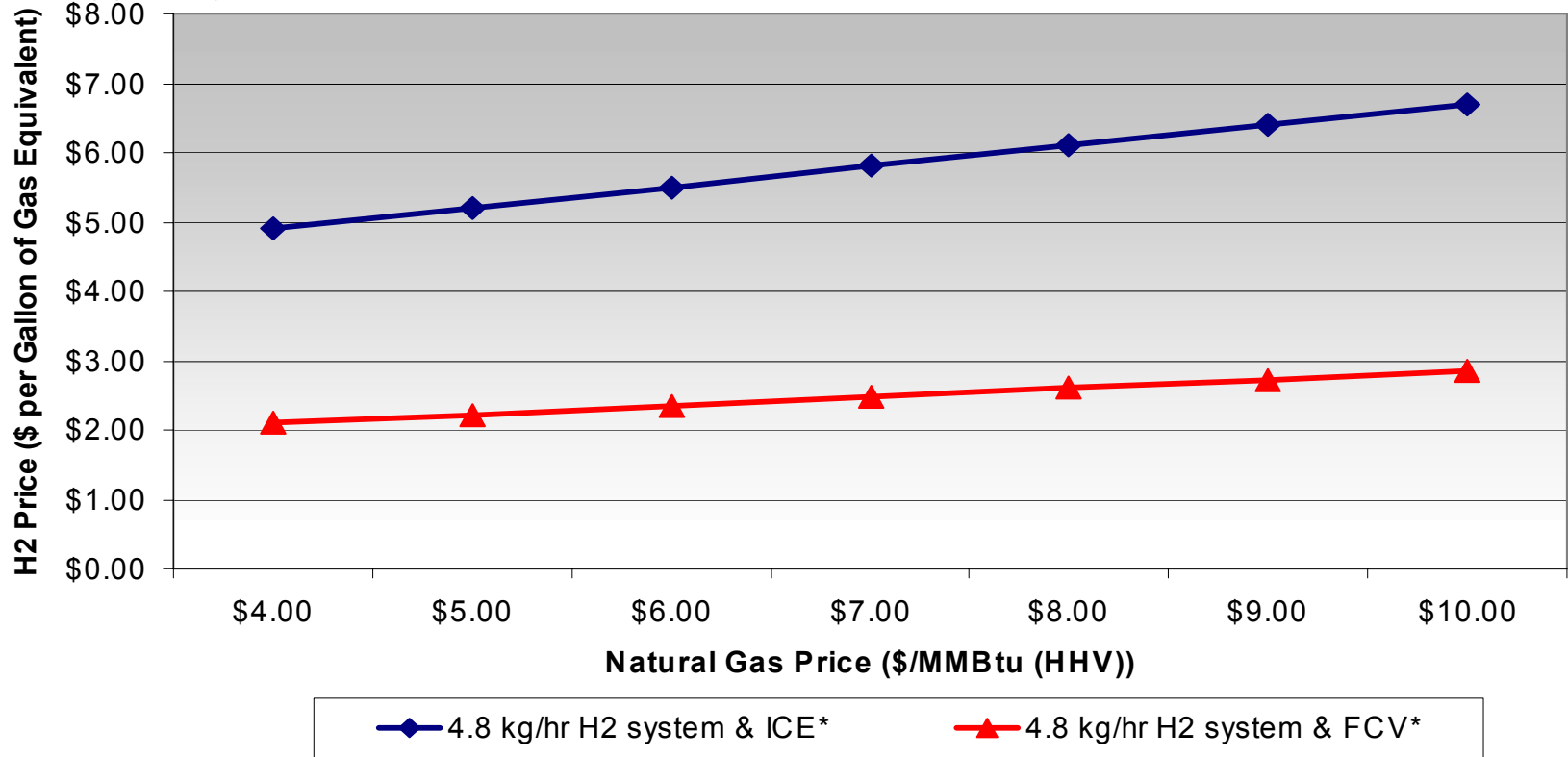
Power: 0.08 \$/kWh

On-Stream Factor: 70%

Contract Life: 20 years

M&R (% of Cap per Year): 3%

## Hydrogen Cost on Gasoline Equivalent Basis



\*Assumes that the cost of H2 storage and fuel cell capital are similar to the current hybrid ICE vehicles. Cost includes compression and dispensing

ICE Hybrid Baseline (MPG gasoline): 43  
FCV MPG Equivalent (GGE MPG hydrogen): 75  
H2 ICE MPG Equivalent (GGE MPG hydrogen): 32  
Percent total cost increase for comp & dispensing: 30%



# ***LCHPP - Future Work***



## ➤ **Remainder of FY 2007**

- Testing of components / proof of design
  - Complete the component testing
    - ◆ High temperature component - reformer, shift, desulfurization, heat transfer, burner, steam generation
    - ◆ High temperature materials
    - ◆ Natural gas compression
    - ◆ Pressure Swing Adsorption (PSA) system
    - ◆ Auxiliary components
    - ◆ Life testing
- Comparative analysis with supply alternatives
- Complete the design of prototype
- Procurement of prototype long-lead materials

# ***LCHPP - Future Work***



- **FY 2008 – Phase III of program**
  - Develop prototype system – components and skid
    - Fabrication and assembly
    - Testing
    - 700 bar hydrogen compression at LAX
- **FY2009-11 – Phase III**
  - Prototype at LAX fueling station
    - Installation and integration
    - Field experience
  - Commercialize system
    - Economic models
    - Manufacturing plan
      - ◆ Production design, fabrication and assembly drawings
      - ◆ Design of jigs and fixtures
      - ◆ Supplier selection

# ***LCHPP - Summary***



## ➤ **LCHPP program**

- Low cost benchmark for small scale hydrogen production
  - Projected cost as low as \$2.75/kg @ 4.8 kg/hr
- Revised schedule
  - Completion of Phase II at end of 2007
  - Completion of Phase III at end of 2011
- Component testing nearing completion
- Prototype procurement underway
- Full size prototype unit available in 2008
  - Life testing of system
- Placement at LAX fueling station
  - 2008 - 700 bar hydrogen compression and dispensing
  - 2009 – Hydrogen system

# Cooperative Efforts



- **US Department of Energy**

- Sponsor

- **Praxair**

- Overall lead

- **Boothroyd-Dewhurst**

- System optimization
- Cost reduction / estimating

- **Diversified Manufacturing**

- Manufacturing
- Prototype development



# Low Cost Hydrogen Production Platform

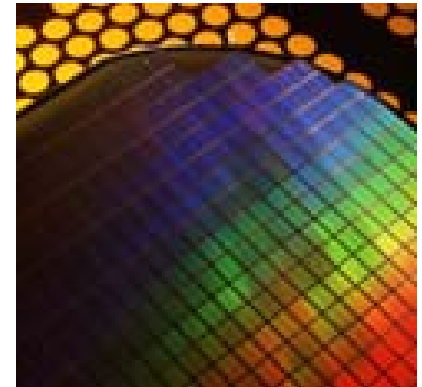
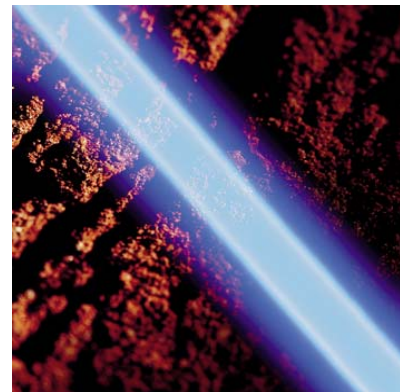
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## Questions?

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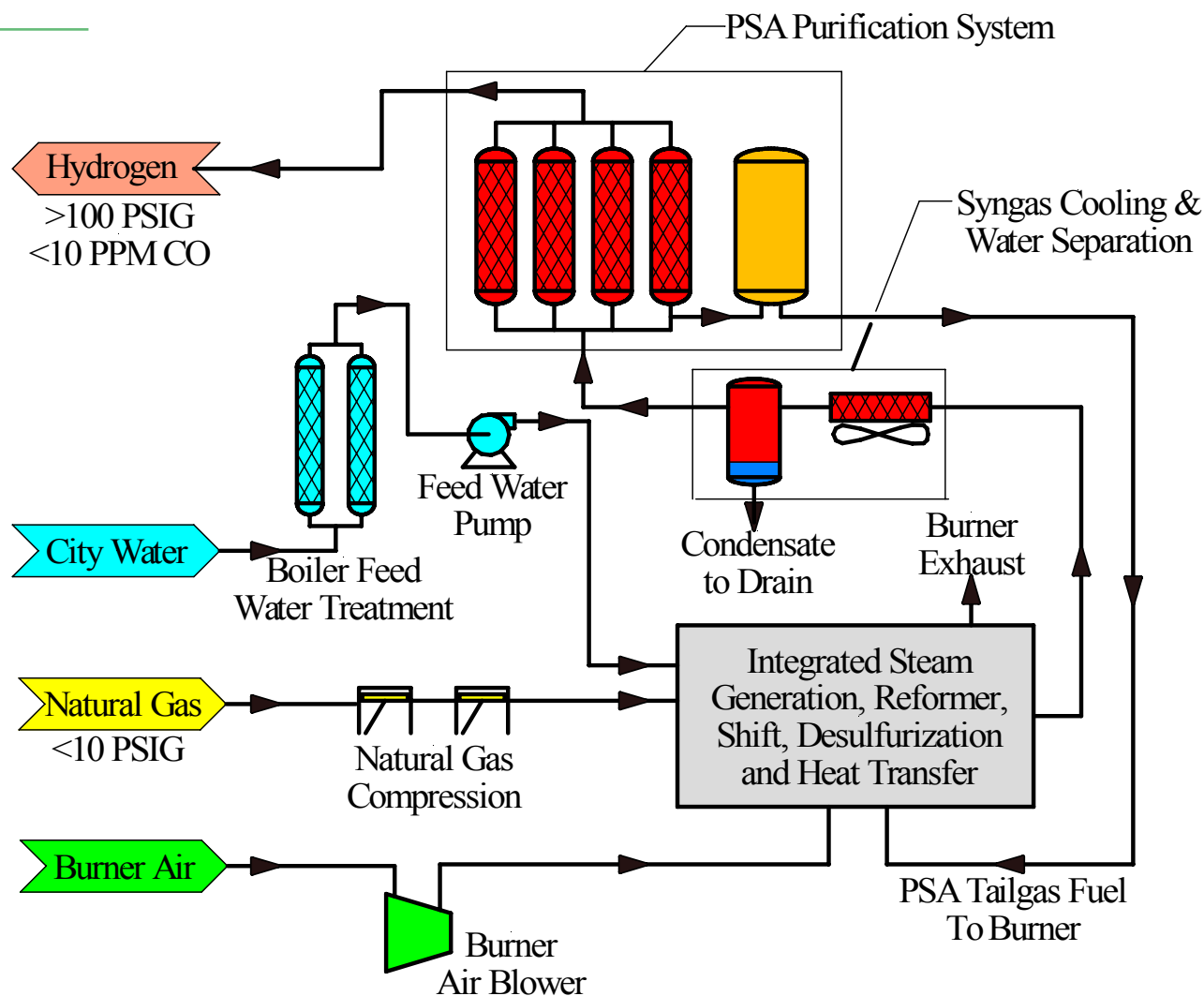


# Praxair Hydrogen



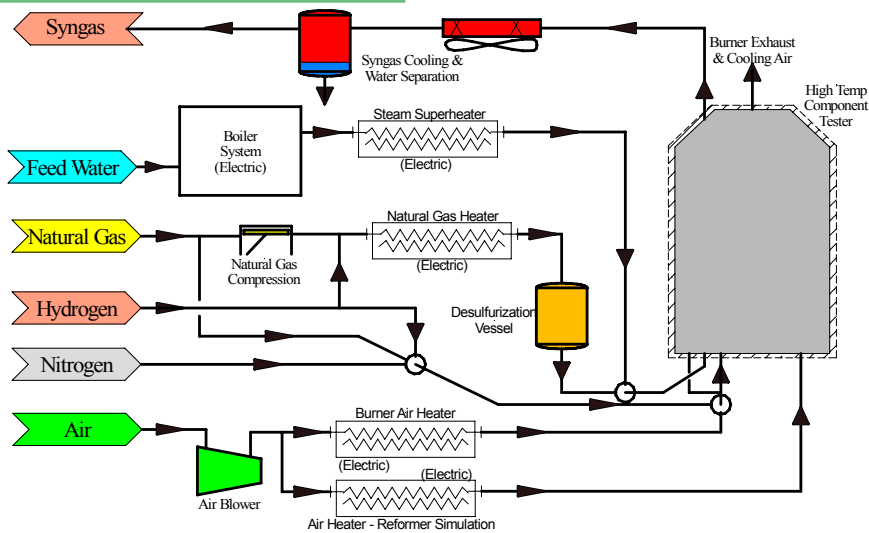
- **Only U.S. hydrogen supplier in all sizes (cylinders to liquid to pipelines)**
  - First industry-financed liquid hydrogen facility (1959)
  - Six large LH<sub>2</sub> plants designed, constructed, and operated
  - Largest capacity single-train LH<sub>2</sub> production system (60 t/d)
  - Four LH<sub>2</sub> plants currently in operation
  - Smallest industrial SMR-based product line (HGS)
- **Over 1 billion SCFD capacity in 2006**
- **Current distribution network:**
  - Over 600 GH<sub>2</sub> and LH<sub>2</sub> customers
  - Over 300 miles of GH<sub>2</sub> pipeline
  - Fleet of liquid and compressed gas trailers
- **First PSA H<sub>2</sub> unit (over 300 designed and built)**

# LCHPP - Skid Process Flow





# Full Scale Test Rig



## System

- Full scale burner
- Air blower
- Electric heaters (4)
- Steam system
- Natural gas, nitrogen and hydrogen gas supplies
- GC gas analysis
- Recording of 24 analog channels and 88 thermocouples
- Testing
  - High temperature functions (reformer, shift reactor, heat transfer, steam generation)
  - Materials
  - Life testing

